Proposed FAA ASR-11 near the Greer, SC NEXRAD

Prepared for
ROC Hotline

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Background

The Federal Aviation Administration proposes to build an Air Surveillance Radar (ASR-11) near an existing NEXRAD site in Greer, South Carolina. The Greer Weather Forecast Office (WFO) has requested the Radar Operations Center (ROC) determine the distance necessary between the NEXRAD and the ASR-11 to minimize mutual interference.

The pertinent parameters are listed below.

Physical Characteristics

WSR-88D Tower Base	286.51 ft (87.3 m) MSL
WSR-88D Antenna Beam Center	114 ft (35 m) AGL, 116 ft MSL
ASR-11 Base	Undetermined
ASR-11 Tower Height	Undetermined (maximum of 85 ft)
ASR-11 Tower Shape	3-sided equilateral triangle shape, trapezoidal from 20 ft base to 3 ft. at top, self-supporting, open construction

Emissions Characteristics

WSR-88D Frequency	2705 MHz
WSR-88D Power	750 KW peak
WSR-88D Antenna Pattern	pencil beam, 45 dBi gain
ASR-11 Frequency	Undetermined
ASR-11 Peak Power	25 kW
ASR-11 Antenna Gain	34 dBi

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Impact of ASR-11 Tower on Radar Performance

The amount of reflected energy is directly related to the range of the ASR-11 from the NEXRAD. In answering the Greer WFO question, a generalized analysis of the necessary range will be performed. The main beam power density is used to give a worst case analysis. Any feed horn altitude differential between the NEXRAD and ASR-11 could dramatically decrease the estimates.

The ASR-11 tower is assembled with 10 ft tower sections. For the purposes of reflections, each section is assumed to have 11 cross members of various shapes and a staircase. Additionally, there is an equipment room located on the highest tower section and the possibility of a radome to cover the antenna. Given the dimensions in the ASR-11 tower blueprints (forwarded by the FAA) and evaluating from a broadside perspective, each 10 ft tower section contributes 4.2 m^2 area, the equipment room contributes 5.5 m^2, and the radome contributes 63 m^2. For an 85 ft tower with equipment room the broadside area for reflection is 41.2 m^2 . This result discards the radome dimensions. Radomes are manufactured for maximum permeability (minimal attenuation and reflection).

Reflections from any structure are extremely dependent on the sight angle and cross member angle. A slight change in either angle can lead to significantly different results. The analysis to follow is a true worst-case as it assumes a maximum reflection based on the broadside area of the tower.

Given the conditions mentioned above, Figure 1 indicates the worst reflections possible by an ASR-11 tower of maximum height if the entire tower is subject to main beam power density. Due to the NEXRAD beam width and scanning elevations, it is unlikely that the entire tower will be subject to the main beam at any time. If the bases of each tower are assumed to be at equal elevations, the main beam power density can be compensated by the NEXRAD antenna pattern (Figure 1)

This is a quick, worst-case analysis of the reflected power from the ASR-11 structure. Figure 1 indicates that reflections from the ASR-11 structure are below the Passive Diode limiter maximum input and at 2 km the compensated reflected power has dropped below the passive diode limiter threshold. For this reason, it is very unlikely that return power from the ASR-11 structure will have a significant impact on the operation of the NEXRAD.

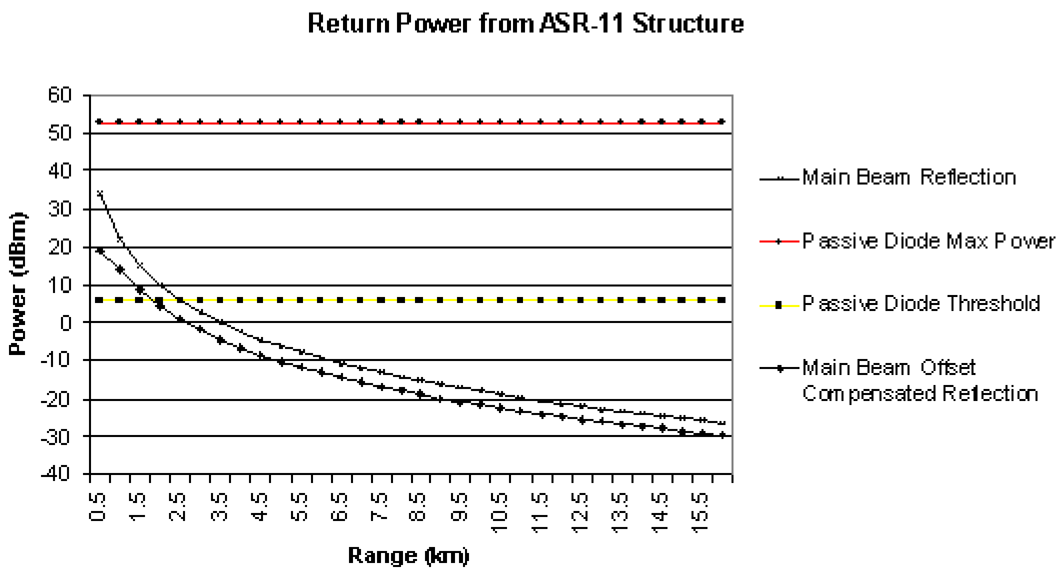

Figure 1 - Power at NEXRAD 2A3J1 from ASR-11 Structure

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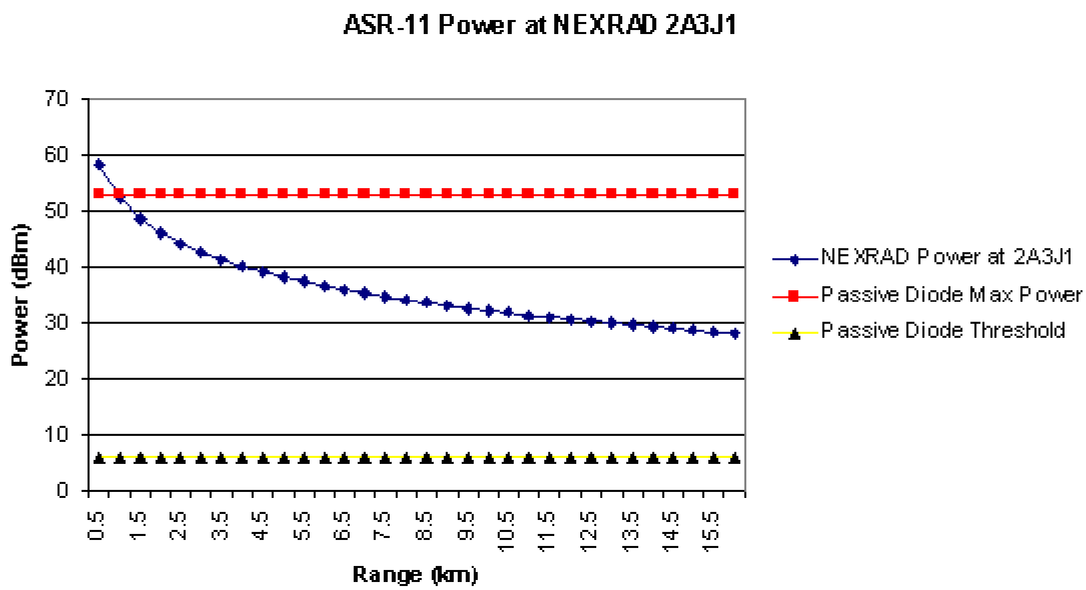

Figure 2 - ASR-11 Main Beam Induced Power at the NEXRAD

Electromagnetic Interference

Electromagnetic Interference is the emissions from one system being received and unintentionally processed by a second system's receiver. The interference can manifest itself as increased system noise, reduced detection capability, false targets, and strobes. Four major factors will effect the amount of EMI recieved by the NEXRAD: range between sites, frequency separation, off-boresight angle, and non-coherent integration losses . The Interference to Noise (I/N) ratio must be less than or equal to 0 dB to eliminate the potential for interference. For the NEXRAD, the noise level is -115 dBm.

The maximum input power to the NEXRAD receiver is set by the passive diode limiter in the NEXRAD receiver front-end. The passive diode limiter in the receiver front end clips the incoming signal as necessary to protect receiver components from damage. The passive diode limiter's threshold is +6 dBm and is capable of handling a maximum of +53 dBm. As can be seen in Figure 2, while a range of 1km will ensure the passive diode limiter is not damaged, even at a range of 16 km the ASR-11 will exceed the passive diode limiter threshold by 22 dB. These are main beam estimations with equal carrier frequencies. It is obvious that frequency separation and increased boresight angle must be utilized to eliminate the potential for EMI.

The NEXRAD contains four major filters for interference rejection and receiver frequency selectivity. Their control specifications are graphed in Figure 4. The x-scale in each graph is the difference frequency. For example, the Greer NEXRAD has a Bandpass Filter tuned to 2780 MHz that has 60 dB of attenuation at 2680 MHz and 2880 MHz.

Without the emission spectrum of the ASR-11 it is impossible to determine the frequency separation necessary for a I/N of 0dB, but some general rules are still applicable. As can be seen in Figure 3, the Bandpass filter is required to provided 60 db of attenuation 100 MHz off center frequency. Typical measurements have shown the Bandpass filter provides 65dB of attenuation at 80 MHz from center frequency. This drops the ASR-11 signal below the passive diode limiter threshold and ensures center frequency backscatter will not be clipped by the passive diode limiter.

At 80MHz off center frequency, the Pre-select filter, Matched filter, and Mixer will attenuate the signal approximately 120dB. This sets the receiver selectivity and ensures the remaining power will not be processed by the NEXRAD.

The boresight angle between the NEXRAD and the ASR-11 can further attenuate the signal level at the NEXRAD. The NEXRAD has an approximate 1 degree beamwidth. As the angle between feed horns increases, the attenuation of the signal also increases. The ASR-11 maximum tower height is 26 meters. The Greer, SC NEXRAD operates on a 30 meter tower. Additionally, the lowest elevation cut by the NEXRAD is currently 0.5 degrees. As Figure 3 indicates, at close in ranges, the signal will be attenuated by approximately 16 dB.

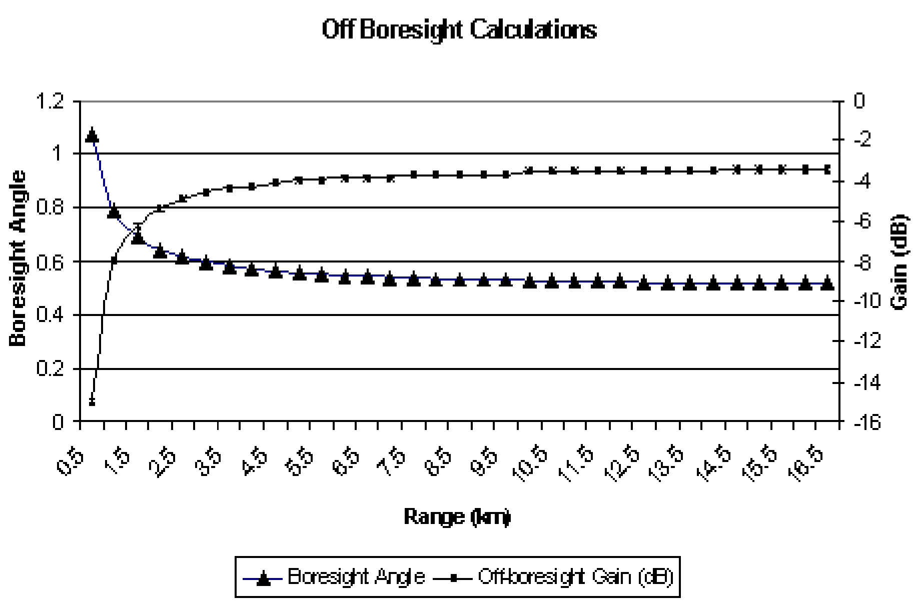

Figure 3 - Off Boresight Adjustments

The possibility of interference is further reduced during the processing of the radar returns. The NEXRAD averages radar returns over a single range bin. Therefore, a dominant return (from the ASR-11 for example) that occurs once within a range bin, will be significantly attenuated due to averaging. If the ASR-11 is operating on a multiple or submultiple of the NEXRAD's Pulse Repetition Frequency (PRF), then the dominant return will be present in all samples for a particular range bin and will bias the return. No specific information regarding the ASR-11 PRF's has been obtained, but the possibility of multiple or submultiple PRF's is remote.

A generalization of the above discussion can be made to minimize the potential for EMI when siting an ASR-11 near a NEXRAD. The ASR-11 should meet the larger of the following two criteria:

1. A frequency separation of 80MHz. The reasoning is outlined above.

2. 150 dBc at the NEXRAD frequency. This takes into account the possibility for varying tower heights and ranges.

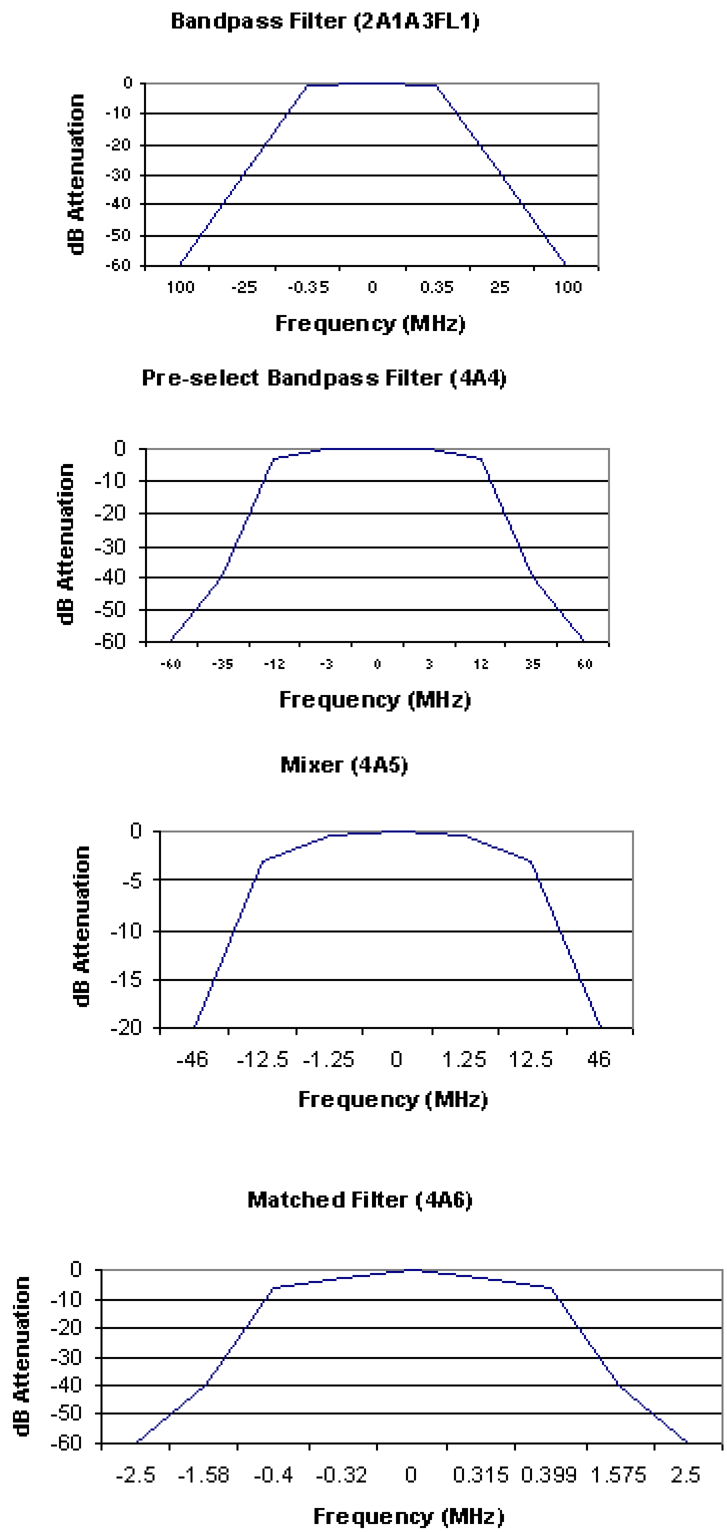

Figure 4 - Filter Characteristics for Receiver Components

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Microwave Radiation Levels

The FCC has established Maximum Permissible Exposure Limits (MPEL) for microwave radiation. Both the NEXRAD and ASR-11 are required to meet these limits. The maximum levels are divided into two categories:

1. Controlled (Occupational Environment): 5 mW/cm2 over a 6 minute period
2. Uncontrolled (General Public exposure): 1 mW/cm2 over a 30 minute period

The NEXRAD and ASR-11 are both pulsed doppler radars. In order to time average there signals (as necessary to measure them against the FCC MPEL's) the following must be considered:

1. Pulse Repetition Frequency (PRF)
2. Pulse Width (PW)
3. Volume Coverage Patterns (VCP)

The PRF and the pulse width determine the duty cycle (dc) of the transmitted RF in the following manner:

$$dc = PRF * PW \qquad \textbf{(1)}$$

Each system has a worst case duty cycle. In the case of the NEXRAD, the upper bound of the duty cycle is set by the physical limitations of the modulator for the klystron. This worst case duty cycle occurs when the NEXRAD is operating under short pulse PRF 8 or long pulse PRF 2. These parameters yield a duty cycle of $2(10^{-3})$. When the duty cycle is applied to the main beam of the NEXRAD, the average power density falls below the FCC Occupation MPEL within 500 meters (see Figure 5). This result is only applicable if the NEXRAD is being commanded to transmit via RDASOT while the antenna is stationary.

The VCP of each system must also be considered and each system, NEXRAD and ASR-11, is substantially different. The NEXRAD antenna is a pencil beam that scans in both elevation and azimuth. The ASR-11 antenna pattern is approximately 30 degrees in elevation and 1.46 degrees in azimuth and scans only along the azimuth.

In the case of the NEXRAD, VCP 31 is the worst case. VCP 31 performs 8 elevation scans (5 unique angles) over a 10 minute period of time in long pulse. Although highly dependent on the range and difference in tower heights, typically the predominant radiation exposure comes from

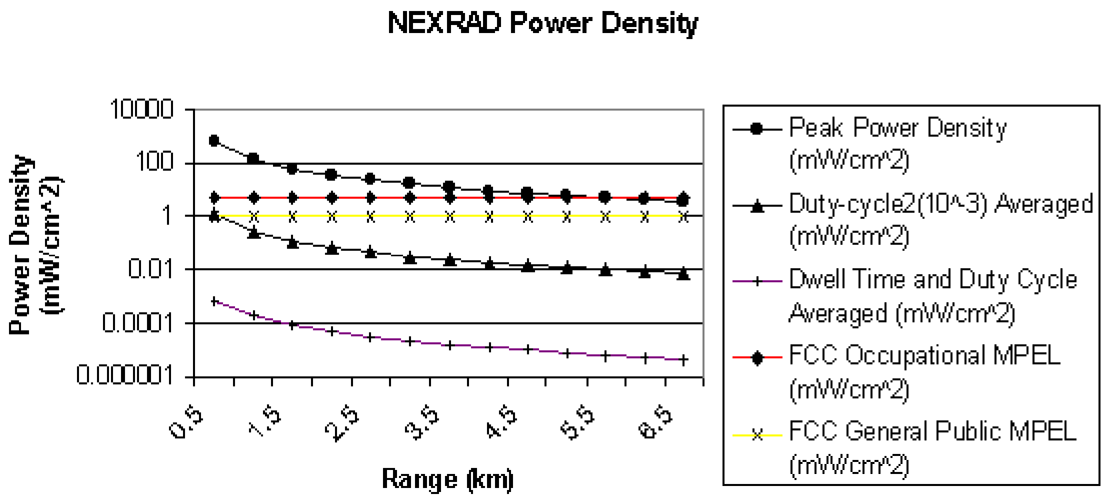

Figure 5 - NEXRAD Power Density compared to FCC MPEL

the lowest elevation angle (0.5 degrees). For this case, an individual will be exposed to the duty cycle averaged power density 6 times in a 30 minute period (two 0.5 degree elevation cuts per VCP; 3 VCP's per 30 minutes). The typical beam width of the NEXRAD antenna is approximately 1 degree and the rotational rate for VCP 31 is .84 RPM (or .2 secs per degree). Therefore, the individual is exposed to the duty cycle averaged power density 1.2 seconds every 30 minutes for a dwell time duty cycle of $6.6(10^{-4})$. With this result factored in, the operational NEXRAD emissions can now be compared to the FCC MEPL's. At a range of 500 meters, the average power density in the main beam of the NEXRAD is far below FCC MEPL's (see Figure 5).

In the worst case scenario (RDA SOT radiating with a stationary antenna), the NEXRAD average power density falls below FCC MEPL at range of 600 meters. It must be understood that this is the main beam of the NEXRAD. If the ASR-11 antenna is lower than NEXRAD antenna, this range will decrease dramatically due to the narrow beam width of the NEXRAD.

The peak transmitted power for the ASR-11 is two order's of magnitude below the NEXRAD's. The FAA website for the ASR-11 indicates the emissions reach FCC MPEL at 43 feet from the antenna.

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Electric Field Interference

MIL-STD-461D outlines the requirements for Radiated Susceptibility to an Electric Field from 10kHz to 40 GHz in section 5.3.16. It indicates that systems "shall not exhibit any malfunction, degradation of performance, or deviation from specified indications" when the system is exposed to a defined electric field. MIL-STD-461D Table IV (RS103 limits) requires a ground based system to withstand a 50 V/m field strength between the frequencies of 1 GHz to 18 GHz. Unlike the FCC MPEL's, the Electric Field Susceptibility is concerned with peak power, not average.

The relationship between power density and field strength is:

$$E = \sqrt{P_D Z_O} \qquad \textbf{(2)}$$

Where:

E = Electric Field Strength (volts/meter)
P_D = Power Density (W/m^2)
Z_0 = Impedance of free space (377 ohms)

The NEXRAD induced field strengths are dependent on the angle between the NEXRAD antenna and the ASR-11 equipment. As indicated in Figure 7, if the ASR-11 tower height is such that it intersects the main beam when the NEXRAD is taking a 0.5 degree elevation cut, RS103 requirements will not be met until the ASR-11 is at a range of 16 km. Yet, if the ASR-11 equipment is at a 0.75 degree depression angle RS103 requirements are satisfied at 3km.

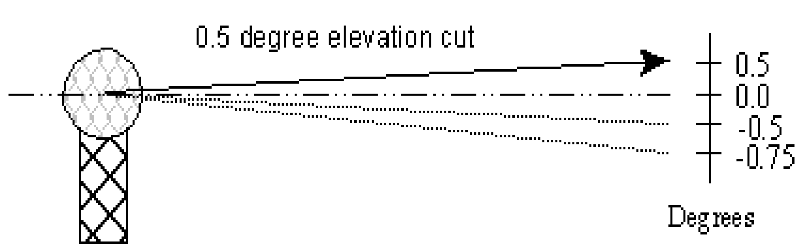

Figure 6 - Angles for NEXRAD Field Strength Calculation

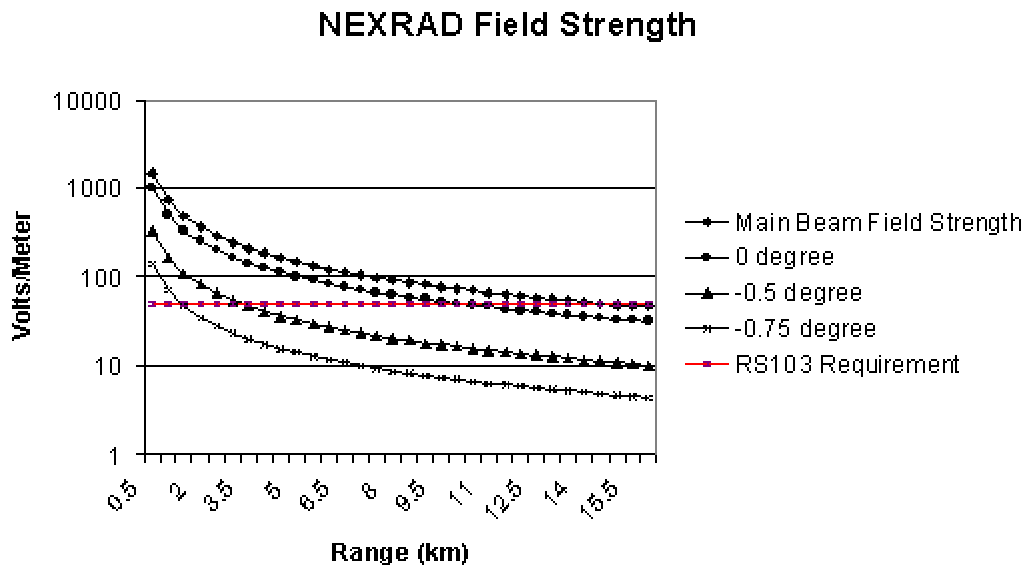

Figure 7 - Field Strength for NEXRAD at 0.5 degree elevation cut

The antenna pattern of the ASR-11 was not provided for this investigation. Therefore off angle calculations cannot be made. In looking just at the main beam of the ASR-11, the field strength falls below RS103 requirements in 1 km (Figure 8). Any consideration of the ASR-11 antenna pattern would only decrease the range.

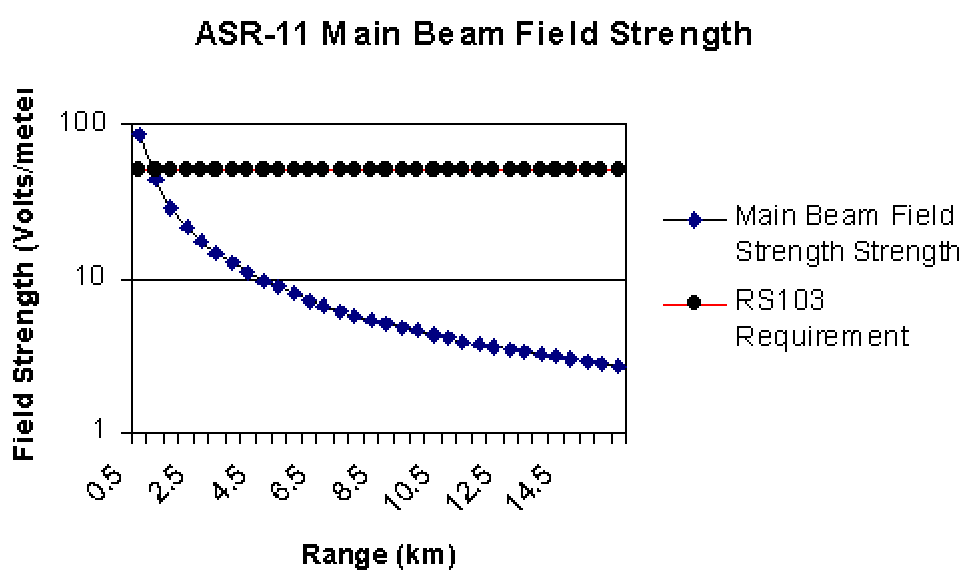

Figure 8 - Field Strength for the ASR-11 main beam

The above analysis of both the NEXRAD and ASR-11 induced field strength indicates that, in order to meet MIL-STD-461D RS103 requirements, the ASR-11 tower height should be lower than the NEXRAD and sized according to Figure 7.

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Summary

1. Reflections from the ASR-11 structure should not have an impact on the operation of the NEXRAD.

2. The ASR-11center frequency should meet the following criteria in order to minimize the potential for Electromagnetic interference:

    1. A frequency separation greater than 80MHz.

    2. 150 dBc at the NEXRAD center frequency.

3. There is no microwave radiation hazard to personnel at the ASR-11 or the NEXRAD.

4. The ASR-11 tower should be kept as far below the NEXRAD main beam as possible to minimize the potential for ASR-11 bulk cable interference induced by the NEXRAD.

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References

[1] MIL-STD-461D, Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility, U.S. Department of Defense, 11 Jan 93.

[2] Sirmans, Dale and Paul Bontempi, WSR-88D Operations Support Facility Redundant Radar Siting Considerations and Recommendations, OSF internal report, 5 Jul 94.

[3] Sirmans, Dale and Paul Bontempi, WSR-88D Radiation and Biological System Considerations, OSF internal report, 4 Oct 94.

[4] 29 CFR Part 1910--Subpart G-Occupational Health and Environmental Control Ch.1910.97 Nonionizing Radiation. See also Subpart R- Special Industries Ch.1910.268 Telecommunications.